Emergent Theory

When it comes to uniting General Relativity with quantum mechanics, Fotini Markopoulou is looking for space in new quantum places.

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by MIKE PERRICONE

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The expression, "There is no time" is a convenient excuse in our busy world. But, in the context of the puzzling quantum world, saying "There is no time" raises a complex scientific issue.

Can the same be said for "space"? What if a scientist were to say, "There is no space," but not in the context of a messy desk or a crowded bookshelf? At quantum scales, could the question of space be equally complex as the question of time?

Fotini Markopoulou, of Canada's Perimeter Institute for Theoretical Physics, doesn't claim to have the answers. But she's intrigued by the questions, and she has some ideas.

EMERGENT THEORIST
Fotini Markopoulou

Among them: What if space does not exist on its own, but instead results from imposing order on other phenomena? Markopoulou draws an analogy with a change of state, or a phase transition, between constituents of matter, a concept common in the field of condensed matter physics, which investigates how macroscopic behavior emerges from a many-body system.

"Think of an ice cube," she says. "It is molecules of water that are ordered in a crystal pattern. Strictly speaking, the ice cube is not real: It is the molecules of water that are real. The ice is one possible phase. Water or steam is another. Similarly, space is an ordering of the constituents of our world."

In other words, Markopoulou is wondering if "there is no space."

Which Makes the Marco Polo Thing Kind of Ironic

With a grant of some $56,000 from The Foundational Questions Institute, Markopoulou is studying models of quantum spacetime, currently using tools and ideas from quantum information theory. For herself and many other theorists, the challenge is to construct a framework where quantum theory and gravity can coexist. She believes current quantum theory actually contradicts our common notions of space itself.

"According to General Relativity," she explains, "gravity is the curving of spacetime by energy and matter. So you put a chunk of matter 'here,' and spacetime curves in a certain way." The problem, according to Markopoulou, is rectifying this aspect of General Relativity with quantum mechanics. "'Here' does not make much sense in quantum theory. According to quantum theory, the chunk of matter is both 'here' AND 'there.' 'Here' curves spacetime one way, and 'there' curves it another way. So, should we say that a chunk of matter produces a quantum superposition of curved spacetimes? If you try to do so, it becomes very difficult to make sense of the outcome."

That's the point where Markopoulou injects an alternative notion: Space emerges from an ordering of its constituents, just as an ice cube emerges from the ordering of water molecules into a crystalline structure.

In other words, "reconciling quantum theory with spacetime," she states, "simply means going into the unordered phase, in which spacetime doesn't really exist."

Through an accident of geography and bureaucracy, Markopoulou carries a name similar to another explorer of uncharted realms: Marco Polo, who wrote of his journeys along the Silk Road to China in the 13th Century. Markopoulou is originally from Athens, Greece, the child of sculptors. "Markopoulou" is the name of a village near where her grandfather was born in the island of Kefallonia in Greece. The registrar made a mistake and added the village name to her grandfather's surname on his birth certificate.

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>
> *- Fotini Markopoulou*

On her own journeys, Markopoulou moved to London, England, to complete her education, and is now headquartered at Perimeter Institute in Waterloo, Ontario. Waterloo recently received a distinctive award: It was named the world's Top Intelligent Community for 2007 by The Intelligent Communities Forum (ICF), an international nonprofit research organization based in New York City, for best exemplifying the development of a prosperous economy based on broadband and information technology.

That environment could not be better suited for Markopoulou's research. In exploring the unordered phase of the physical conditions that might give rise to space, Markopoulou will be using methods of information theory originally developed to build models of quantum computers.

The Right Tool for the Job

The classical computing unit of information, the *bit*, exists as 0 or 1. It is limited to those two possibilities. But in quantum computing, the information bundles, called qubits, can exist as 0, or 1, or both 0 and 1 simultaneously. A quantum qubit can thus take many steps at once, instead of just one step at a time. Quantum computing offers a natural fit for studying models of a universe made from a large network of small quantum mechanical systems.

"Such stuff is the bread and butter of quantum computing," Markopoulou says. "There have been great tools developed that one can use to understand the models. There are cool ways to think about some of these tools. For example, an important part of quantum computing is quantum error correction. The qubits of a quantum computer are subject to noise, which would mess up the system. Quantum error correction, or encoding, is the subject that studies ways of protecting the qubits from the noise."

Protecting information from noise is especially useful, she says, in exploring the Planck scale, where ultimate questions of time and space could be answered – or further complicated. At the Planck Scale, high energies (10^{19} giga electron volts, or GeV) and minuscule distances (10^{-35} meters) mean that quantum gravity dominates, and normal notions of time and space go out the window. So, figuring what goes on at the Planck scale is among the paramount challenges for physicists, and Markopoulou hopes to enlist quantum error correction as an ally.

PHASE CHANGE Melting ice

"If there is physics at the Planck scale," she asks, "why don't we see it? You can think of the Planck scale constituents as the qubits, and the Planck scale physics as the noise. The fact that we can ignore Planck scale physics must mean that there is a good reason why this noise does not matter. By analogy to quantum computation, what we see is what nature encoded."

Seth Lloyd of MIT, who is Director of the W.M. Keck Center for Extreme Quantum Information Processing (xQIT), sees both value and promise in the approach. He says Markopoulou has taken "a bold step in attempting to derive a quantum theory of gravity from an underlying theory of quantum information processing."

He continues: "In her theory, space and time are emergent structures: what is important is the underlying computation. Dr. Markopoulou's theory provides potential solutions to several long-standing problems in quantum gravity. Perhaps most important, her theory is straightforward, accessible, and engaging."

Can her idea be proven? That's the hard part, as Markopoulou acknowledges. The cosmos itself is the natural laboratory for probing the ultimate nature of space, though Markopoulou knows the investigative tools will need new levels of sophistication.

But if the theory could be proven, she says, "We'll be the first generation ever to see the universe without seeing space."